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EFFECTS OF HYPOHYDRATION OR COLD EXPOSURE AND RESTRICTED FLUID INTAKE UPON COGNITIVE PERFORMANCE

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UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

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Controlled studies of cognitive performance in cold environments are rare. The present study examined the effects of initial hydration state upon cognitive performance during cold exposure. Five tests (Coding, Number Comparison, Computer Interaction, Pattern Comparison, and Grammatical Reasoning) were used to assess the cognitive performance of 36 male Marine volunteers. Assessment methods and four of the tests were adapted from the Navy's program, Performance Evaluation Tests for Environmental Research (PETER); the Computer Interaction Test was developed at USARIEM. All subjects practiced the tests extensively the 3 days before the cold exposure. Each test was usually given 5 times per day for 4 minutes per administration. Computer Interaction was practiced 5 times per day for 7 minutes.

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19. Abstract (Continued)

Two groups of 18 subjects each were studied, 21 days apart, for 10 consecutive days. The second group of subjects was dehydrated by 2.5% of their body weight by severe fluid restriction and exercise-induced sweating the day before the cold exposure; the first group was normally-hydrated. All subjects spent 5 days in an environmental chamber where temperatures during the day were -23 to -25°C with 4 km/h winds and night conditions ranged from -4 to -10°C without wind. In the cold the subjects wore protective Arctic Uniforms; afterwards, recovery was evaluated for 27 hours. All cognitive assessment was interspersed with extensive physical work. Subjects exercised vigorously each day by walking, running, and pulling simulated loads on a treadmill. Handware was worn during precold, cold, and recovery testing. The subjects' fluid intake was controlled and limited throughout the study.

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Technical Report

No. 15/86

Effects of Hypohydration or Cold Exposure and Restricted Fluid Intake Upon Cognitive Performance

by

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FOREWORD

Most people know that inadequate water intake limits a person's capacity to exercise, perform heavy physical work, and lose excess body heat. It is not well known that hypohydration can also hinder one's ability to think and evaluate information. The present study investigated the effects of hypohydration upon cognitive performance at room temperatures and in extreme cold. The military volunteers also performed vigorous exercise.

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ABSTRACT

Controlled studies of cognitive performance in cold environments are rare. The present study examined the effects of hydration state upon cognitive performance at room temperature and during cold exposure. Five tests (Coding, Number Comparison, Computer Interaction, Pattern Comparison, and Grammatical Reasoning) were used to assess the cognitive performance of 36 male Marine volunteers. Assessment methods and four of the tests were adapted from the Navy's program, Performance Evaluation Tests for Environmental Research (PETER); the Computer Interaction Test was developed at USARIEM. All subjects practiced the tests extensively during the 3 days before the cold exposure.

Two groups of 18 subjects were investigated, 21 days apart. Each was studied for 10 consecutive days (3 days pre-cold, 5 days cold, 2 days recovery). On the third day the second group of subjects was dehydrated (2.9% of their body weights) by severe fluid restriction and exercise-induced sweating and rehydrated to 98% of their body weight, before the cold exposure the next day. The first group was normally-hydrated on day 3 and at the beginning of the cold exposure. All subjects spent 5 days in an environmental chamber where temperatures during the day were -23 to -25°C with 4 km/h winds and night conditions ranged from -4 to -10°C without wind. In the cold the subjects wore protective Artic Uniforms; afterwards, recovery was evaluated for 27 hours. All cognitive assessment was interspersed with vigorous physical exercise, i.e. walking, running, or pulling simulated loads on a treadmill. Mittens or gloves were worn during precold, cold, and recovery testing. Fluid intake for all subjects was limited throughout the study.

Hypohydration (a deficit of body fluids) at room temperatures or cold exposure with limited intake of fluids impaired cognitive performance. The five tests assessed different processes and skills; all, except Grammatical Reasoning, were sensitive to 2.5% hypohydration (at room temperature) and to cold exposure. Before hypohydration both groups' performances were comparable on the Coding, Number Comparison, and Computer Interaction Tests. The performance of the hypohydration group, before the cold exposure, was 70-90% of the normally-hydrated group (15th administration) and 79-90% of their prior peformance when they were hydrated (6th & 7th administrations). These differences were statistically significant, except for Grammatical Reasoning. Both groups' performances were comparable during cold exposure and 71-81% of the normally-hydrated group's performance at room temperature. Performance during cold exposure was not affected by the initial hydration state but recovery lagged in the subjects hypohydrated before cold exposure. Both hypohydration and cold exposure impaired cognitive performances. The similarity of performance impairments observed for hypohydration at room temperatures and for cold exposure suggests that 2.5% hypohydration produces impairments as great as those seen for extreme cold exposure.

1. INTRODUCTION

Hypohydration, i.e. a deficit of body fluids, can profoundly affect behavior, especially when combined with elevated body temperatures. Heat exhaustion or heat stroke and death may result from marked hypohydration (1,6,16). Changes in emotion (6), aggression (6), cognitive performance (16), jet fighter crew performance (4), video target acquisition (10), and hand steadiness, dexterity, and coordination (9,13,18) have also been reported for hypohydration. Some studies have also shown negative results. Number Comparison and Choice Reaction Time performance were not affected by 3% hypohydration (2) nor were visual reaction times to central and peripheral stimuli for 2.5 or 5% hypohydration (12).

Most hypohydration studies have examined physiological changes occurring during heat exposure; few have investigated cognitive or psychomotor performance. Studies of hypohydration and mental performance in cold environments are even rarer and many studies of cold do not investigate hypohydration as an independent variable. Typically, performance studies in the cold evaluate tasks which require hand steadiness, dexterity, and coordination, e.g. (13,18).

The purpose of this study was to investigate the effects of hypohydration upon cognitive performance under normal and cold temperature conditions. Cognitive performance was evaluated by five tests, shown sensitive to 4600 m simulated high altitude in a prior investigation.

2. METHOD

Thirty-six active duty, male Marine Corps personnel from Camp LeJeune, NC, were the subjects of this study. All were fully informed

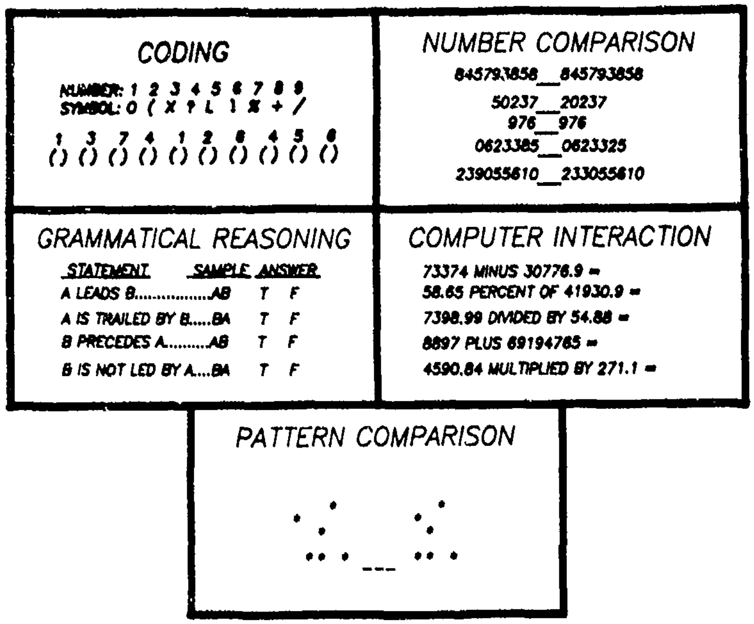
volunteers. Their average age was 22.0 ± 4 (SE) years and weight 76.54 ± 1.12 (SD) kg.

Our investigation was part of a larger collaborative study with personnel from the Naval Submarine Medical Research Laboratory, Groton, CT, and other personnel from USARIEM in which hypohydration indices (17), physical work performance (14,17), hand cooling (17), and map plotting performance were evaluated. Two groups of 18 subjects each, were studied 21 days apart. Each group was studied over 10 consecutive days in a large climatic chamber at the US Army Natick Research, Development, and Engineering Center, Natick, MA, where subjects were exercised and tested during the day and housed at night. In the first group studied, subjects were fully hydrated before the cold exposure; the second group was hypohydrated 2% by body weight. For our purposes, these groups were regarded as normally-hydrated and hypohydrated (predehydrated).

Testing on days 1-3 of each study was at 20 to 27°C and was used to establish baselines. On day 3 subjects in the hypohydrated group lost 3% of their body weight by severe fluid restriction and sweat losses over 10 hours. In the evening they were rehydrated to 2%. On days 4-8 all soldiers wore the protective Arctic uniform and were challenged with -23 to -25°C and 4 km/h winds from 0700 to 1530 h. During these evenings, conditions warmed to -4 to -10°C and there was no wind. Normal temperature was restored and rehydration was begun on days 9-10. A program of vigorous physical activity was maintained on days 1-8. Subjects were given adequate food but were limited in their fluid intake.

Five paper and pencil tests of cognitive performance were administered during the study. Each test had 15 alternate forms and sample items are shown in Figure 1.

Figure 1. Sample items from the cognitive tests used in the study.



The Computer Interaction Test was developed at USARIEM. The other tests were adapted from the Navy's Performance Evaluation Tests for Environmental Research, i.e. PETER (3,5). The Coding Test requires that subjects write symbols for different numbers from the legend at the top of the page. This test is similar to manual procedures for encoding sensitive military radio communications. Subjects performing the Number Comparison Test indicate if two numbers are the same or different. Such test demands are similar to comparing part numbers, map grids, or numbers on property decals.

Grammatical Reasoning is a test of verbal comprehension in which the subjects decide if a two letter series (sample) is described correctly by a statement. This test evaluates understanding of various grammatical transformations of language, e.g. "A precedes B", "A is preceded by B". Grammatical Reasoning performance evaluates processes similar to those for understanding written information, e.g. orders, technical procedures, and training manuals. The Computer Interaction Test evaluates a person's global

transactions with a "computer" system. Subjects use a 12-digit desk top calculator with a liquid crystal display (Radio Shack EC-2004) to solve problems like those in Figure 1. A plastic plate covered several calculator function keys not required during testing. The Computer Interaction Test requires actions like those of some military personnel who use computer keyboard and display systems. In general, information is entered into the calculator, one of six sequential operations is performed, and display information is transcribed onto the test form. The computed result sometimes requires rounding, depending upon the answer's characteristics.

Each Pattern Comparison problem consists of two patterns with the same number of asterisks, i.e. 6-8. On some problems, a single asterisk in one of the patterns will be displaced slightly. Subjects indicate if the two patterns are the same or different. Such demands are like those for evaluating if vehicles have been moved between successive reconnaissance photographs.

The Arctic chamber and other study activities created a dynamic setting with distractions and special challenges for cognitive testing. Cognitive testing was interspersed between exercise intervals and the requirements of other investigators. Typically, 9 subjects were tested while the other 9 subjects were exercised. Testing sessions usually began 2-3 minutes after 15 minutes of heavy exercise. We did not attempt to reduce the noise from the two large 5-person treadmills or the extraneous sounds produced by the exercising group during cognitive testing. When subjects were released to other studies, they were tested (if possible) when they returned.

All tests were timed. Computer Interaction was evaluated for 7 minutes per administration; all other tests were evaluated for 4 minutes.

Subjects were urged to work as quickly and accurately as possible. No subjects completed all problems on any test in the time allowed. Subjects were instructed formally before each test was given on day 1. To provide individual feedback, data sheets were given to subjects showing their sequential test scores (number of problems attempted and number of errors) on days 1 and 2 and at the end of day 3. If individual error rates were greater than 10% after 8-10 administrations, comments written on the data sheet and/or verbal feedback suggested the subject work slower to reduce errors.

Each cognitive test was practiced several times the first few days to produce stable and maximum performance. Both groups were given each test 5 times daily on days 1-3, except group 1 which was tested 4 times on day 1. Subjects were tested twice daily at 0800 and 1300 h during the cold exposure with restricted fluid intake (days 4-8) and recovery (days 9-10) conditions. Subjects wore mittens or gloves during most cognitive testing. Group 2 wore the Artic mittens with woolen inserts on days 3-9. Group 1 wore military gloves with woolen inserts during cognitive testing on days 2, 3, and 4; on days 5-9 they wore Artic mittens with inserts after the gloves proved inadequate for the cold. Wooden pencils, 1 cm in diameter, were used to complete the tests.

The mean number of problems correct per minute was calculated to provide a single performance score for each test. A correction factor to penalize for guessing was used with the Number Comparison, Pattern Comparison, and Grammatical Reasoning Tests. On days 4-8, the two daily administrations of each test were averaged to yield a single score.

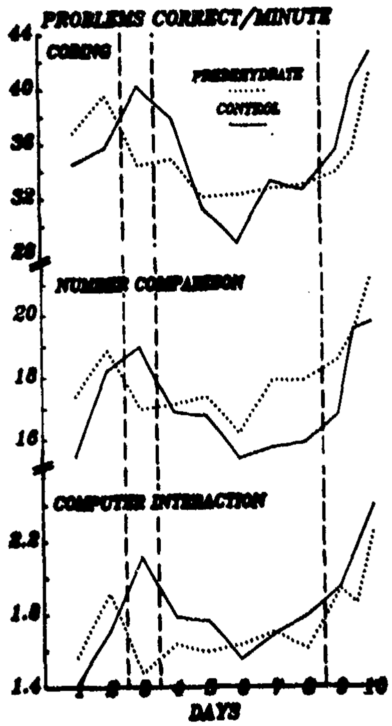
Body weights were determined at 0600 h daily shortly after awakening and voiding of urine. Subjects were weighed in their briefs in an adjacent,

heated room. On day 3 subjects were weighed nude 3-4 times to document hydration state. Control body weights, i.e. 100% body weight, were the average of day 1 and 2 weights. Percent change from 100% body weight was also calculated. All data were analyzed using 2V repeated measures analysis of variance programs created with BMDP statistical software (7). The statistical significance of individual data points was determined with Tukey's HSD statistic for selected multiple comparisons (15). Statistical significance was specified as $p \leq 0.05$.

3. RESULTS

Day 3 fluid restrictions imposed in the hypohydration group were effective. After 8 hours, the group was 2.1% dehydrated as inferred from changes in body weight; after 10 1/2 hours, the group was 2.9% dehydrated. We assume subjects were dehydrated ~2.5% at 9-10 hours during cognitive testing. In contrast, after 5 hours (before fluids were replaced) the body weight of the normally-hydrated group decreased 1%. After 10 1/2 hours, this group was dehydrated 0.7%.

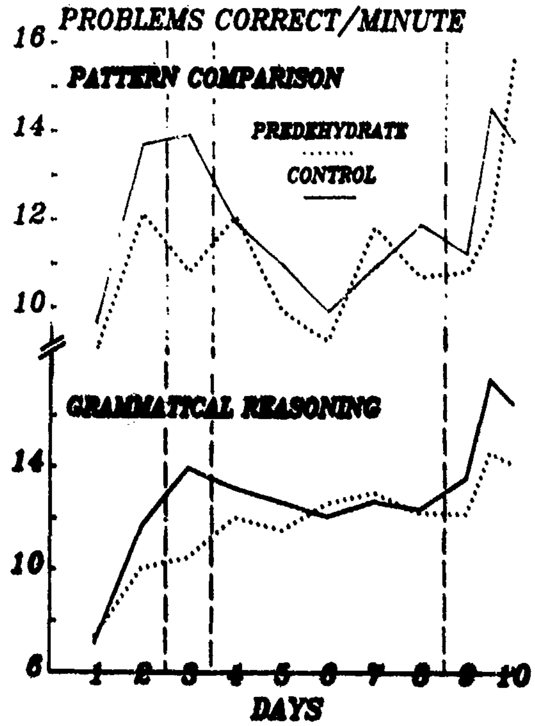
Figure 2. Cognitive performance on the Coding, Number Comparison, and Computer Interaction Tests for conditions of training, 2.5% hypohydration at room temperatures, cold exposure with restricted fluid intake, and recovery.



Performances on the Coding, Number Comparison, and the Computer Interaction Tests are shown in Figure 2. Day 1 and 2 values are the averages for test administrations 2+3 and 6+7, respectively; day 3 data are from the 15th administration. On day 3 (room temperatures) Coding, Number Comparison, and Computer Interaction performances were significantly impaired by 14.2, 10.5, and 30.4% in the hypohydrated group ($p \le 0.01$). Comparable data are shown for the Pattern Comparison and Grammatical Reasoning Tests (Fig 3). Normally-hydrated group values for day 3 were adjusted to compensate for significant ($p \le 0.05$) group differences (admin. 8) before performing the Pattern Comparision and Grammatical Reasoning

statistical analyses. After adjustment, the Pattern Comparison performance of the predehydration group was impaired by 14.6% ($p \leq 0.01$). Grammatical Reasoning performance was not affected by 2.5% hypohydration.

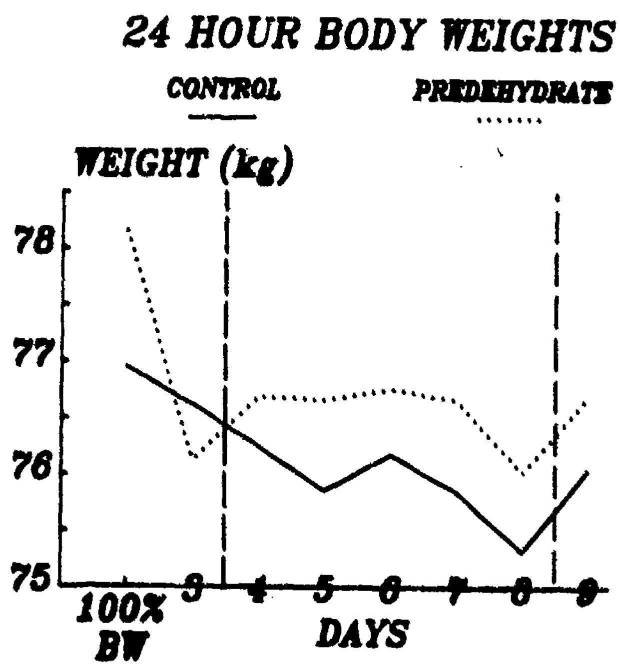
Figure 3. Cognitive performance on the Pattern Comparison and Grammatical Reasoning Tests for conditions of training, 2.5% hypohydration at room temperatures, cold exposure with restricted fluid intake, and recovery.



Body weight fell during the cold exposure with restricted fluid intake (Fig 4). Before the cold challenge (end of day 3), the normally-hydrated group was 0.4% lighter than their 100% body weight values, but they lost another 1.7% during days 4-8 in the cold. All their body weight changes, except day 3, were significantly different from their 100% body

weight ($p \leq 0.01$). In contrast, the hypohydration group's weight loss was 2.7% just before the cold challenge and they only lost 0.2% more by day 8. Their within-group weight losses were significantly different than control ($p \leq 0.01$). Because the initial weight loss of group 2 was not restored, between-group weight losses were significantly greater in group 2 on days 4 ($p \leq 0.01$), 6 ($p \leq 0.05$), 7 ($p \leq 0.05$), and 8 ($p \leq 0.05$). After 24 hours of recovery, the body weights of groups 1 & 2 were still significantly less, i.e. 1.1 and 1.9%, than their controls ($p \leq 0.01$).

Figure 4. Baseline (100%) and successive body weights during the cold exposure with restricted fluid intake. Control subjects began the cold exposure normally-hydrated; whereas, other subjects were hypohydrated.



Figures 2 and 3 also show the impact of cold exposure and fluid restriction upon performance. Performance on the Coding, Number Comparison, Computer Interaction, and Pattern Comparison Tests was significantly impaired from baseline ($p \leq 0.01$) for the combination of cold exposure and fluid restriction, with a few exceptions. Coding did not differ significantly from baseline (day 4, normal-hydration group) nor did Number Comparison on days 5, 7, and 8 (hypohydration group). Consistent with the 2.5% hypohydration data, at no time was Grammatical Reasoning impaired significantly in the cold. Maximal performance decrements on the Coding, Number Comparison, Computer Interaction, and Pattern Recognition Tests during the cold exposure and fluid restriction condition were 28.2, 19.2, 27.1, and 33.6% of the normal-hydration group's control performance.

We also compared the hypohydrated group's performance on each test during the cold exposure and fluid restriction condition with their day 3 performance when they were dehydrated. Only once (Pattern Comparison, day 6) was performance during the cold exposure and fluid restriction condition more impaired than that observed on day 3 for 2.5% hypohydration at room temperatures ($p \leq 0.01$). On all other occasions, performance impairments for cold exposure and for 2.5% hypohydration at room temperature were similar.

When normal temperature was restored and rehydration was begun (day 9), the two groups were compared. Although after 6 h Number Comparison performance in the predehydration group did not differ from the baseline performance of the normally-hydrated group, Computer Interaction ($p \leq 0.05$), Coding ($p \leq 0.05$), and Pattern Comparison ($p \leq 0.01$) performances remained impaired. The next morning, 19 hours later, performance on these three tests was equivalent or superior to baseline.

After 6 hours, the performance of the normally-hydrated group on the Coding, Number Comparison, Computer Interaction, and the Pattern Comparison Tests was not significantly different than their day 3 control values. Their Grammatical Reasoning performance at 6 hours actually exceeded baseline performance ($p \leq 0.01$).

The hypohydration and normal-hydration groups were compared at equivalent times during the study for possible group differences. During the cold exposure and fluid restriction condition the performance of both groups on the five tests was remarkably similar, except for the hypohydration group's greater performance on Number Comparison on day 7 ($p \leq 0.01$) and day 8 ($p \leq 0.05$). On the other four tests and at all other times during the cold exposure and fluid restriction condition, the groups' performances were similar.

Similar group trends emerged during recovery. After 1 and 24 hours the groups' performances were not different on any of the tests, except the hypohydrated group's performance was greater on Pattern Comparison ($p \leq 0.01$). As noted earlier, after 6 hours the hypohydrated group had not fully recovered. Hence, between-group comparisons at 6 hours showed the normal-hydration group's performances exceeded that of the hypohydration group on the Computer Interaction ($p \leq 0.01$), Coding ($p \leq 0.01$), Pattern Comparison ($p \leq 0.01$), and Grammatical Reasoning ($p \leq 0.05$) Tests. Performance on Number Comparison did not differ.

The two groups were also compared with data collected before hypohydration. We only compared administrations 5 and 8 (day 2), but both groups' performances on the Number Comparison and Computer Interaction Tests were similar. Coding performances were similar on administration 5 but the predehydration group had greater scores on administration 8 ($p \leq 0.01$). On

Pattern Comparison the hypohydration group had greater scores initially ($p \leq 0.01$); the normal-hydration group did later ($p \leq 0.05$). On Grammatical Reasoning the normally-hydrated group's performance was greater ($p \leq 0.01$) on both administrations.

4. DISCUSSION

Hypohydration at normal room temperatures and cold exposure with fluid restriction produced significant performance impairments on the Coding, Number Comparison, Computer Interaction, and Pattern Comparison Tests. The Grammatical Reasoning Test was not affected. The changes observed on the four tests are interesting since the tests require varied processing (e.g., numbers, symbols, patterns, words) and have different attentional, spatial, memory, and hand coordination requirements. This finding suggests varied cognitive processes and skills are affected by hypohydration at room temperatures or by cold exposure with fluid restriction. Our data contrast with earlier studies that showed no effects on Number Comparison Performance after 3% hypohydration in 14 subjects (2) or visual reaction times after 2 1/2 or 5% hypohydration (12).

Before hypohydration was induced, there were performance differences on the Pattern Comparison (admin. 8) and Grammatical Reasoning Tests (admin. 5 & 8) in the the hypohydrated and normally-hydrated groups. To offset the higher than expected scores for the normally-hyorated group on each test, their scores (admin. 15) were decreased by the group difference observed earlier (admin. 8). Even with this conservative adjustment, Pattern Comparison Performance was impaired by 2.5% hypohydration; however, Grammatical Reasoning was not.

We were surprised that Grammatical Reasoning Performance was not impaired by hypohydration. Our study at 4600 meters simulated high altitude demonstrated impairments and the test was sensitive to other stressful conditions in the literature. We suspect that our subjects had not received enough training and feedback. This is supported by the facts that during recovery Grammatical Reasoning Performance was much greater than baseline and it was equivalent in the two groups at the end of the study. Grammatical Reasoning is one of the more difficult of our tests for subjects to understand.

Cold exposure and restricted fluid intake also impaired the same four cognitive tests that were affected by 2.5% hypohydration at room temperatures. There were some exceptions such as Coding performance (day 4, normally-hydrated group) and Number Comparison Performance (days 5, 6, and 8, hypohydration group). We have no hypotheses or explanations for these nonsignificant data. The fact that Grammatical Reasoning was not affected contrasts greatly with a study reporting enhanced performance during a cold exposure (8).

The literature suggests that performance decrements in the cold are probably due to changes in manual dexterity and distracting stimuli (11). Our test battery emphasizes thinking and processing of information so manual dexterity would be less important for our tests than those that measure psychomotor performance, e.g. (13,18). Our experience with cold exposure also suggests that competing activities, e.g. moving the hands or feet to keep them warm, are probably also important factors.

Our data indicate that each group's performance on the four tests were not significantly different during the cold exposure and restricted fluids condition except for days 7 and 8 on the Number Comparison Test. The

earlier substantial performance changes observed for hypohydration at room temperature and the timecourse of the performance changes and the consistent difference in weight loss between the two groups during the cold exposure suggest dehydration effects in the normally-hydrated group were probably overwhelmed by the effects of cold exposure.

Impairments on the Coding, Number Comparision, Computer Interaction and Pattern Comparison Tests for the cold exposure and restricted fluid intake condition were comparable to those for 2.5% hypohydration at room temperatures. This finding suggests 2.5% hypohydration at comfortable temperatures can have effects upon cognitive performance which are as great as those observed at -23 to -25°C. A second consequence of hypohydration is suggested by our finding that performance impairments were present after 6 hours of recovery on three of the four tests sensitive to hypohydration. This suggests that cognitive performance impairments from < 3% hypohydration may persist even after subjects are partially rehydrated.

5. CONCLUSIONS

1. Subjects hypohydrated 2.5% of their body weights at room temperature exhibited impaired cognitive performances on the Coding, Number Comparison, Computer Interaction, and Pattern Comparison Tests. The Grammatical Reasoning Test was not affected.

2. Performance also deteriorated on the same four tests during a 5-day cold exposure (-23 to -25°C) with restricted fluid intake.

3. Performance decrements observed for 2.5% hypohydration (room temperature) were as large as those observed during cold exposure with restricted fluid intake.

4. Performance during the cold exposure with restricted fluid intake was not different in subjects who began the challenge normally hydrated or hypohydrated (2% of body weight).

5. During recovery, subjects hypohydrated 2% before cold exposure were impaired longer on three of the four cognitive tests than the normally-hydrated group.

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7. ADDENDUM

Substantial portions of this paper were presented previously and published elsewhere as noted below:

Banderet, L.E., D.M. MacDougall, D.E. Roberts, D. Tappan, M. Jacey, and P. Gray. 1984. Effects of dehydration or cold exposure and restricted fluid intake on cognitive performance. In Proceedings Workshop on Knowledge Needed for the Development of Predictive Models of Military Performance Decrements Resulting from Inadequate Nutrition, Washington, D.C. National Academy Press: Washington, D.C. (in press).

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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